Mucool Test Area
Cryostat & cooling-loop design

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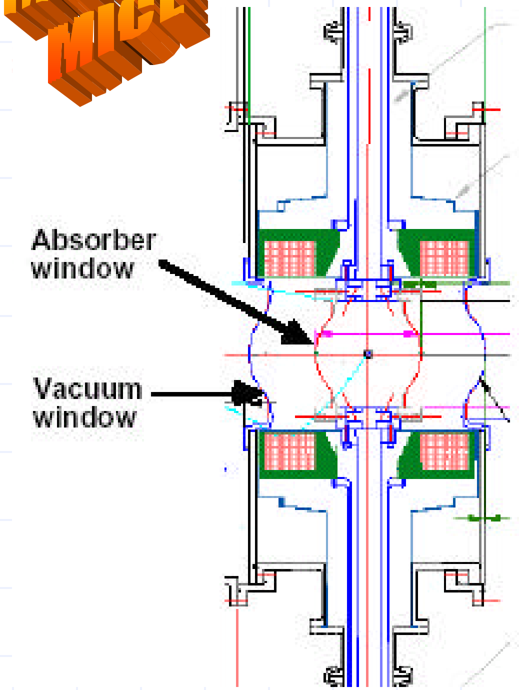
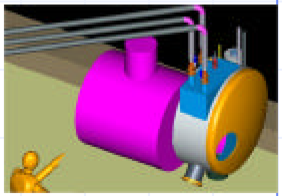
Fermilab/Beams Division/ Cryogenic Department/ Engineering and Design Group

MuCool / MICE

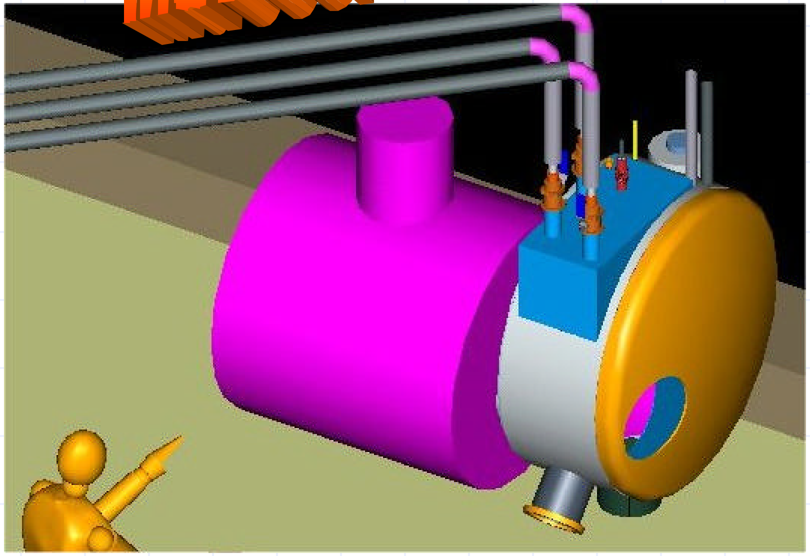
02/21/03

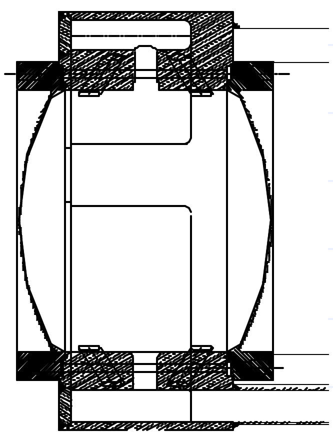
MuCool
MICE

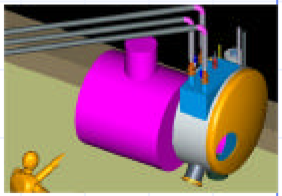




MuCool Test Area

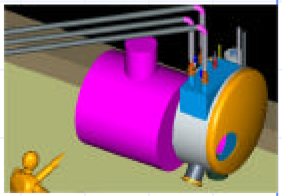






Cryostat design

Specifications



The Linac beam will deposit within the absorber a maximum heat deposition of **150 Watt**

P= 1.2 atm,

T= 17 K

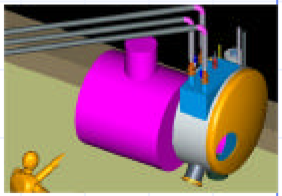
$\Delta\rho < 5\%$

$\Delta T \sim 1$ K (could be 3 K)

- **Safety gudelines:**

1. " Guidelines for the Design, Fabrication, Testing, Installation and Operation of LH2 Targets–20 May 1997", Fermilab by Del Allspach et al.
2. Fermilab ES&H (5032)
3. code/standard ASME, NASA
4. NEC (art 500)
5. CGA

Materials



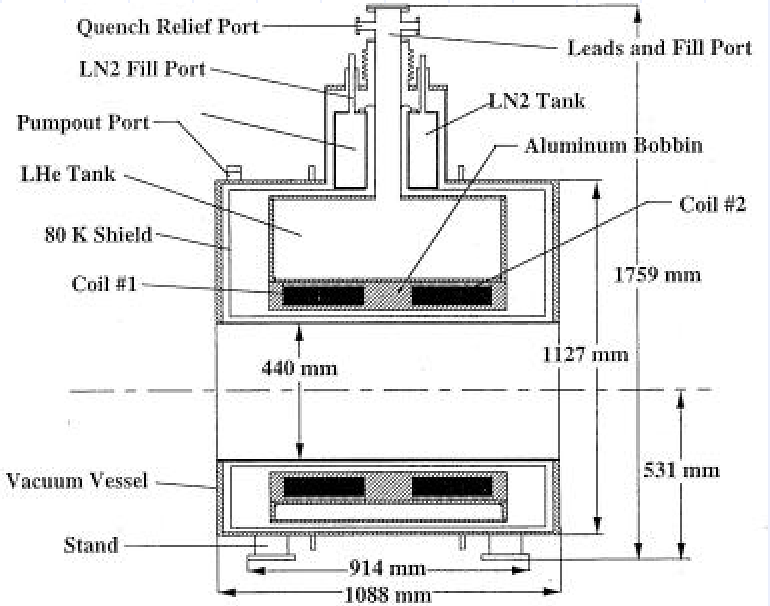
1. Caltech LH2 pump

- Max LH2 mass-flow = 450 g/s (0.12 MPa, Tin=17 K)
- ΔP total < 0.36 psig

References :

1. *"A high power liquid hydrogen target for parity violation experiments", E.J. Beise et al., Research instruments & methods in physics research (1996), 383-391"*
2. *" MuCool LH2 pump test report", C. Darve and B. Norris, (09/02)*

2. Lab-G magnet



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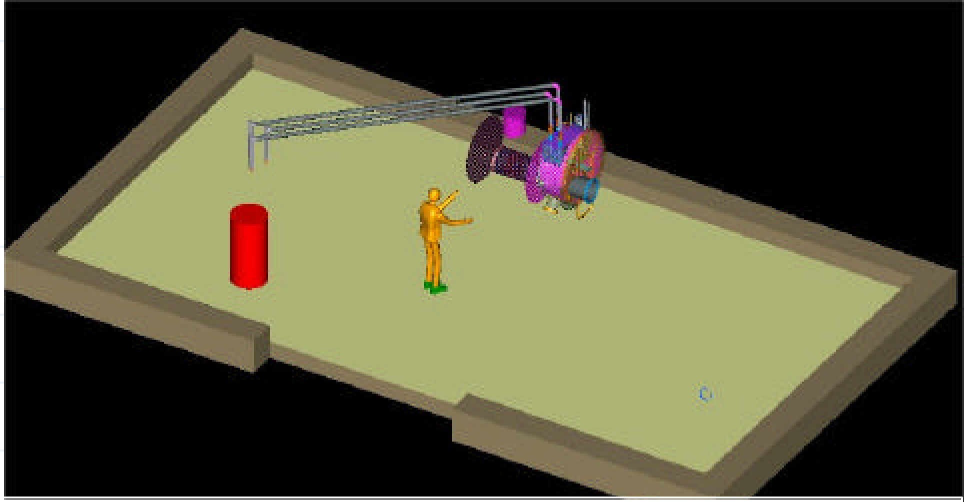
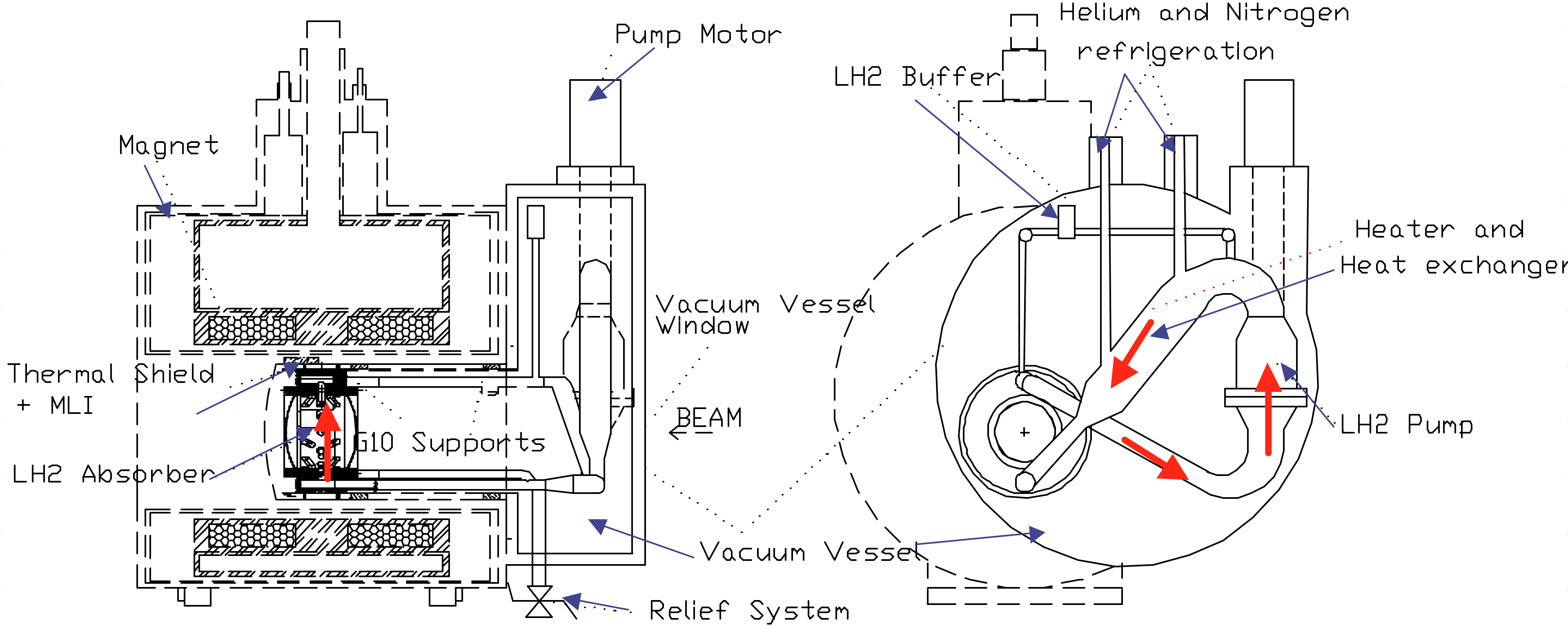
Conceptual Design





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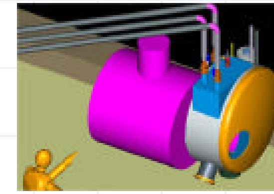
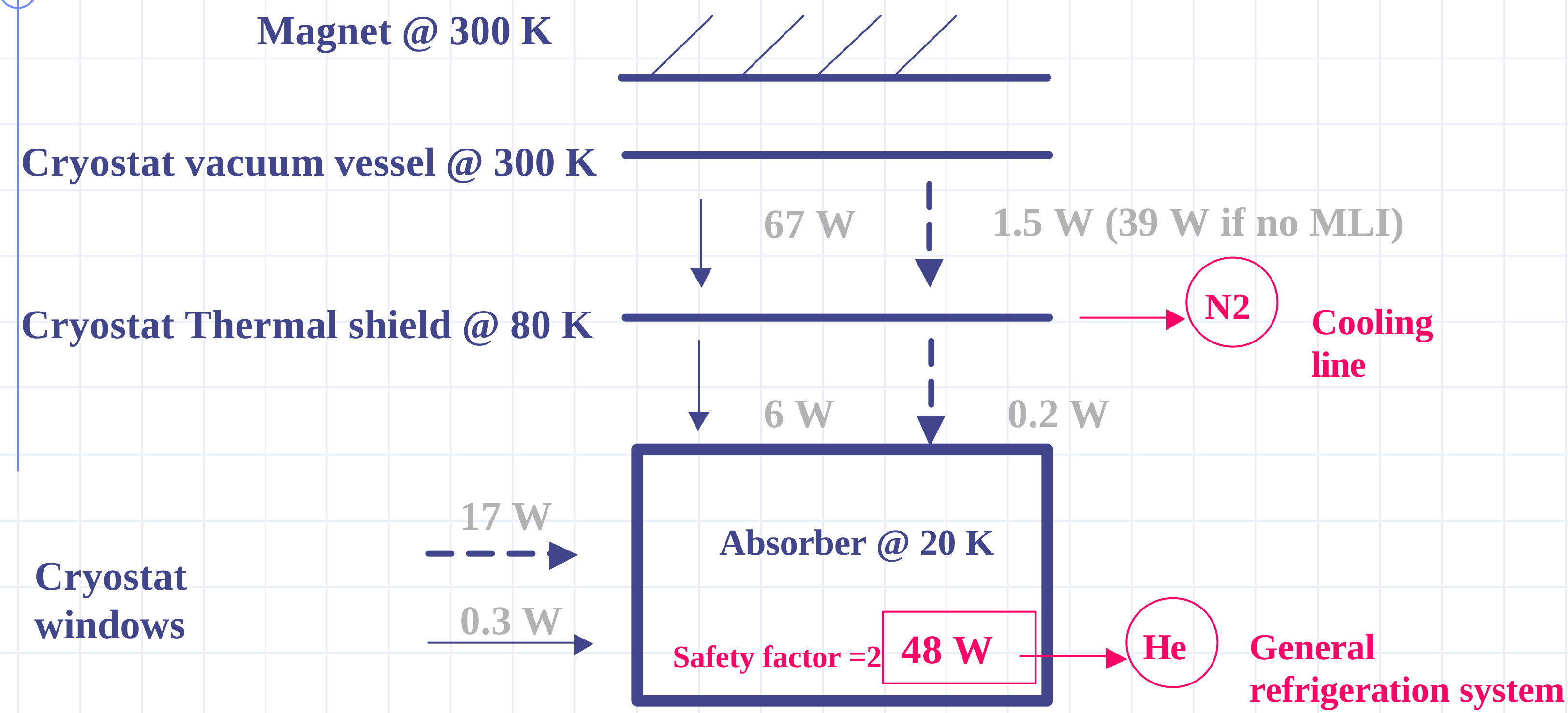
Heat load calculations





Legend:

- Heat transfer by conduction through supports
- Heat transfer by radiation and through MLI

Heat load (W)	80 K	17 K
Mechanical Supports	67	6
Superinsulation	1.5	0.2
Cryostat windows	-	17
LH2 pump	-	50
Total	68.5	73.2

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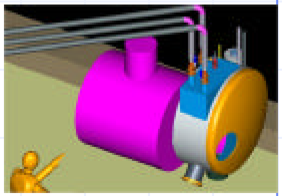
“Materials list” - Cryostat Design



The MTA cryostat is mainly composed of:

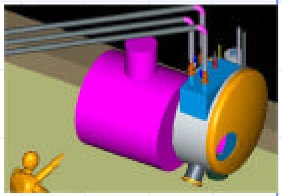
Cryogens used:

- **LN2 to cool Thermal shield**
- **Ghe to cool LH2 cryo-system**
- **LH2 to cool cryo-system (beam+static)**

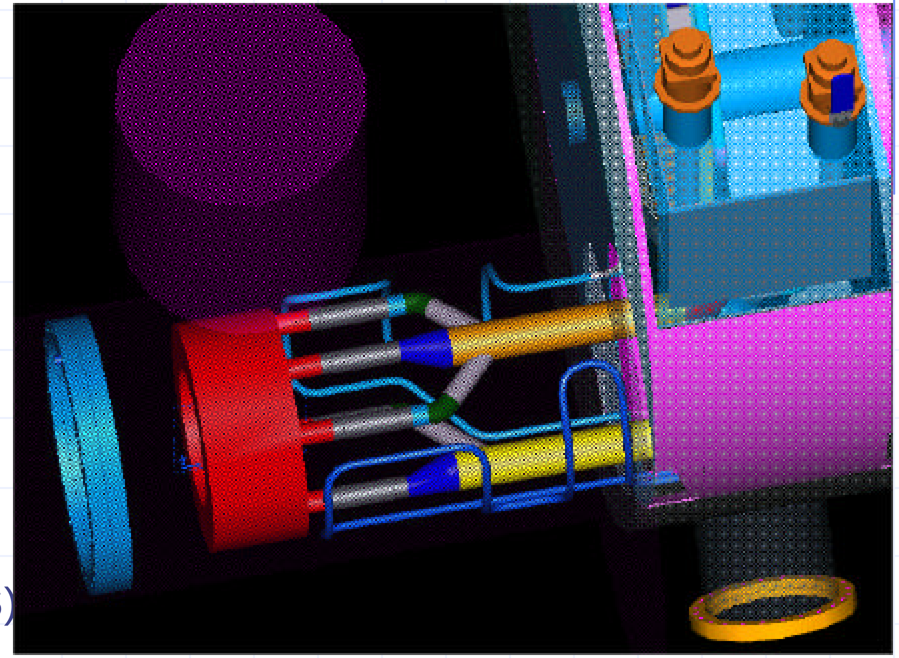
	P (psia)	T(K)	m_max (g/s)
N2	45.0	77-80	5
He	32.0	14-17	26
H2	17.6	17-20	450

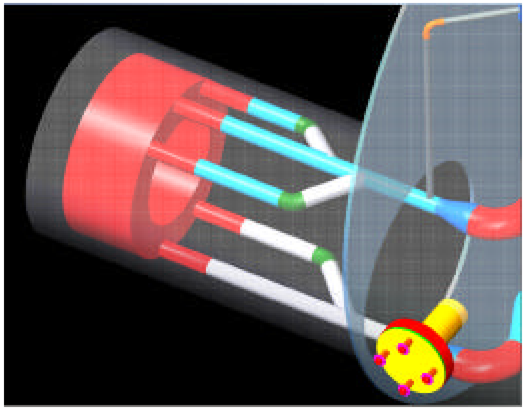
- **LH2 Absorber**
- **Vacuum vessel**
- **Thermal shield**
- **Hydrogen buffer**
- **Vacuum window**
- **Transfer lines**
- **Safety devices**
- **Heat exchanger**
- **LH2 pump**
- **Motor**
- **Supports**
- **Equipment**

Assembly



- ✓ Vacuum vessel: MAWP=25 psig;
SS, 16 IPS Sch10, 48 IPS Sch10
  - Dome (SS, 0.25 inch)
  - Plate (SS, 0.25 inch)
  - Central support (1 inch)
- ✓ Thermal shield (Al) +MLI (Al, Mylar)
  - Aluminum braids
  - Aluminum cooling line
- ✓ He, H2 and N2 Piping (SS, 1-2 inch IPS)
- ✓ Hydrogen buffer(SS,ϕ 3 inch)
- ✓ Vacuum window Flange, Al, SS, Al seal
- ✓ Vacuum pump flange
- ✓ Relief vacuum





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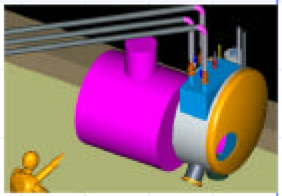
Pressure safety devices



Pressure relief valve – LH_2 : II C 4 a (iii)

- Relief pressure (10 psig or 25 psid)
- Sized for max. heat flux produced by air condensed on the **LH_2** loop at 1 atm.

2 valves ACGO
ASME code
Capacity = 52 g/s

=> 0.502 inch^2
Redundant

Pressure relief valve – Insulation vacuum : II D 3

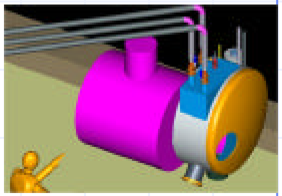
- MAWP (15 psig internal)
- Capable of limiting the internal pressure in vacuum vessel to less than 15 psig following the absorber rupture (deposition of 25 liter in the vacuum space)
- Vapor evaluation q= 20 W/cm2
- Take into account DP connection piping and entrance/exit losses

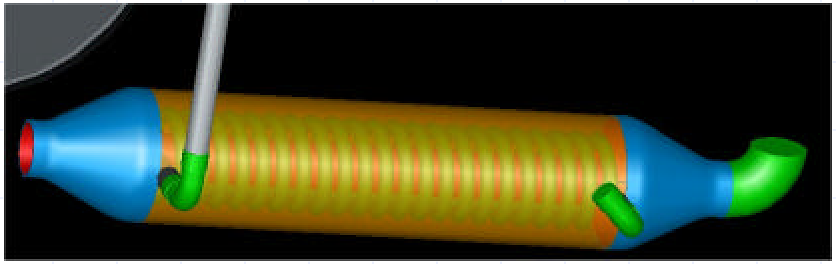
3 parallel plates (FNAL design)
Calculated Capacity = 197 g/s

=> 2 inch
Redundant

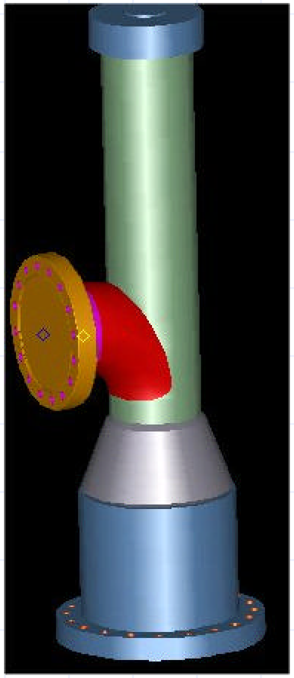
Relief system must be flow tested

MTA Cryostat Design





1. **Heat exchanger assembly**
   - ✓ Coil (copper, ϕ 0.55 inch)
   - ✓ Outer shell (SS, 6 inch tube)
2. **LH2 pump assembly**
   - ✓ LH2 pump and shaft with foam
   - ✓ Motor outer shield
3. **Absorber assembly:**
   - ✓ Black/Wing windows and manifold design
   - ✓ Interface of the systems
     - Bimetallic junction
     - Indium Doubled-seal
4. **Supports**
   - ✓ G10 spider and rods



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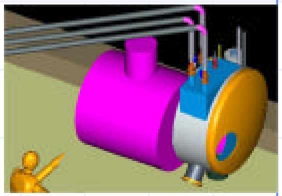
MTA Cryostat Design

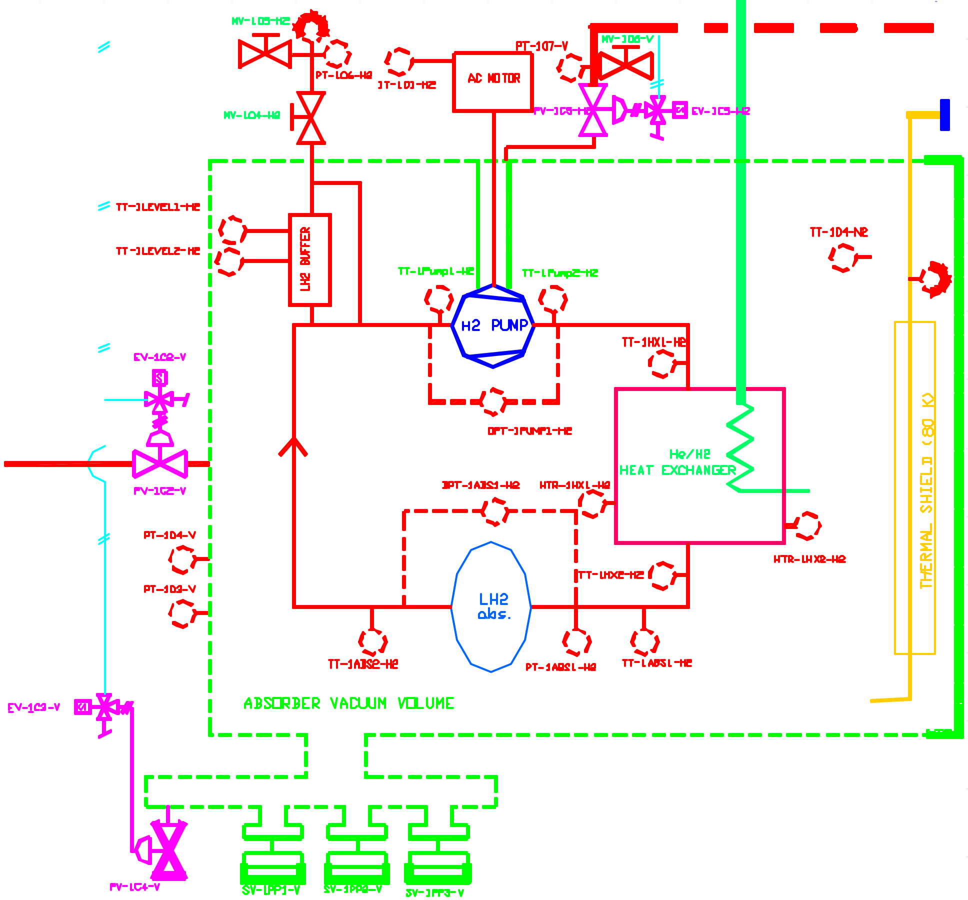


6. Equipment

- ✓ Pressure transducers
- ✓ Temperature sensors
- ✓ Flowmeter
- ✓ Heater
- ✓ Valves and actuators
- ✓ Vacuum pump cart
- ✓ Other instrumentation

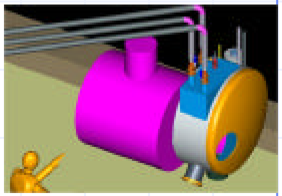
Safety constraints:

- N2 guard
- Low excitation current
- Interlocks



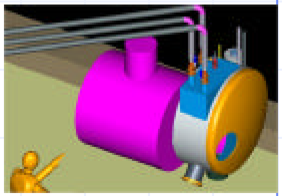
✓Minimum spark energies for ignition of H_2 in air is 0.017 mJ at 1 atm, 300 K
✓Lower pressure for ignition is ~1 psia (min abs. 0.02 psia // 1.4 mbar)

Comments/questions



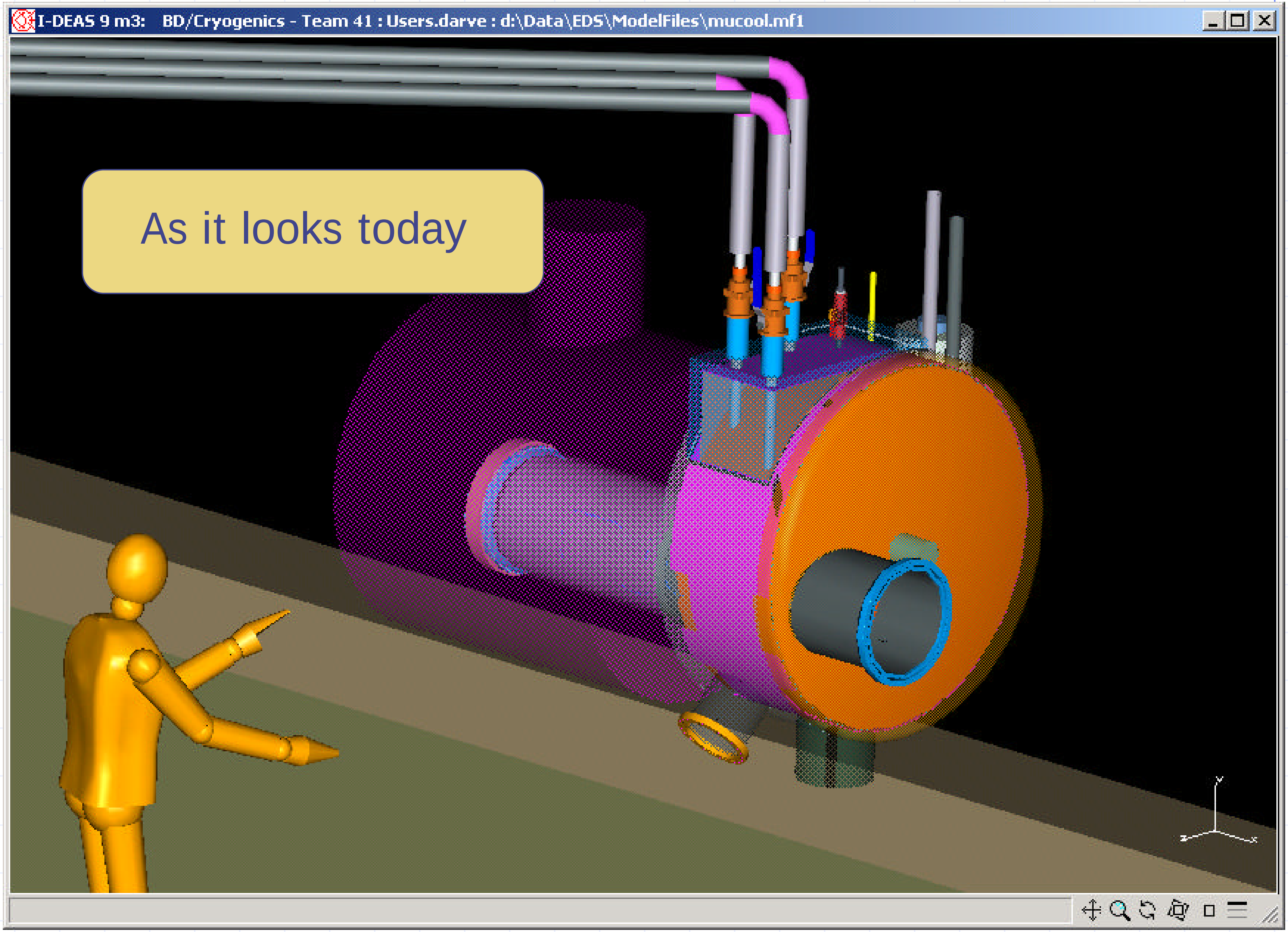
1. Cryo-pumping
2. Position of cryostat vacuum windows
3. Interfaces: atmosphere or vacuum behind cryostat vacuum windows
4. Absorber Instrumentation routing and ports

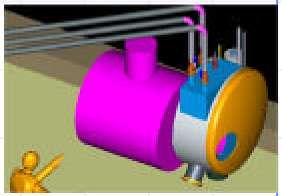
MTA Cryostat design – Conclusions



Cryostat 3D model current focuses:

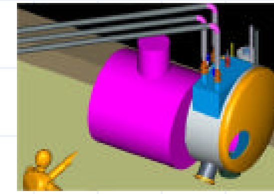
- ✓ Change orientation of the heat exchanger
- ✓ Final LN2 cooling system
- ✓ Implementation of vacuum windows
- ✓ Heater implementation
- ✓ Supports
- ✓ Instrumentation implementation


I-DEAS 9 m3: BD/Cryogenics - Team 41 : Users.darve : d:\Data\EDS\ModelFiles\mucool.mf1
As it looks today



Cooling-loop design

(Introduction to Oxford analysis)



Cooling-loop Design

Manifold optimization of nozzle distribution and geometry

mass flow

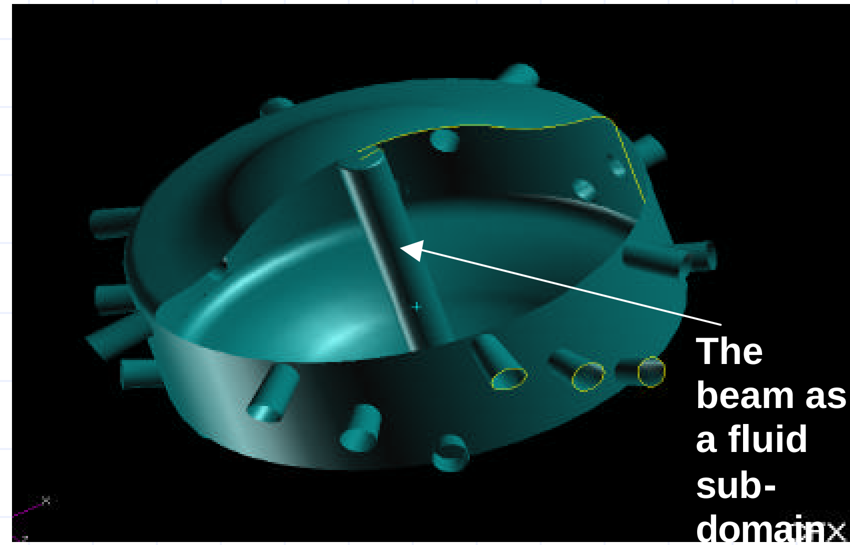
Velocity at nozzle

ΔP

Given geometry, Power and nozzle distribution

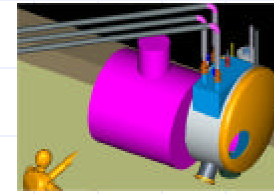
Heat transfer coeff.

ΔT



Flow Simulation by Wing Lau / Stephanie Yang (Oxford)

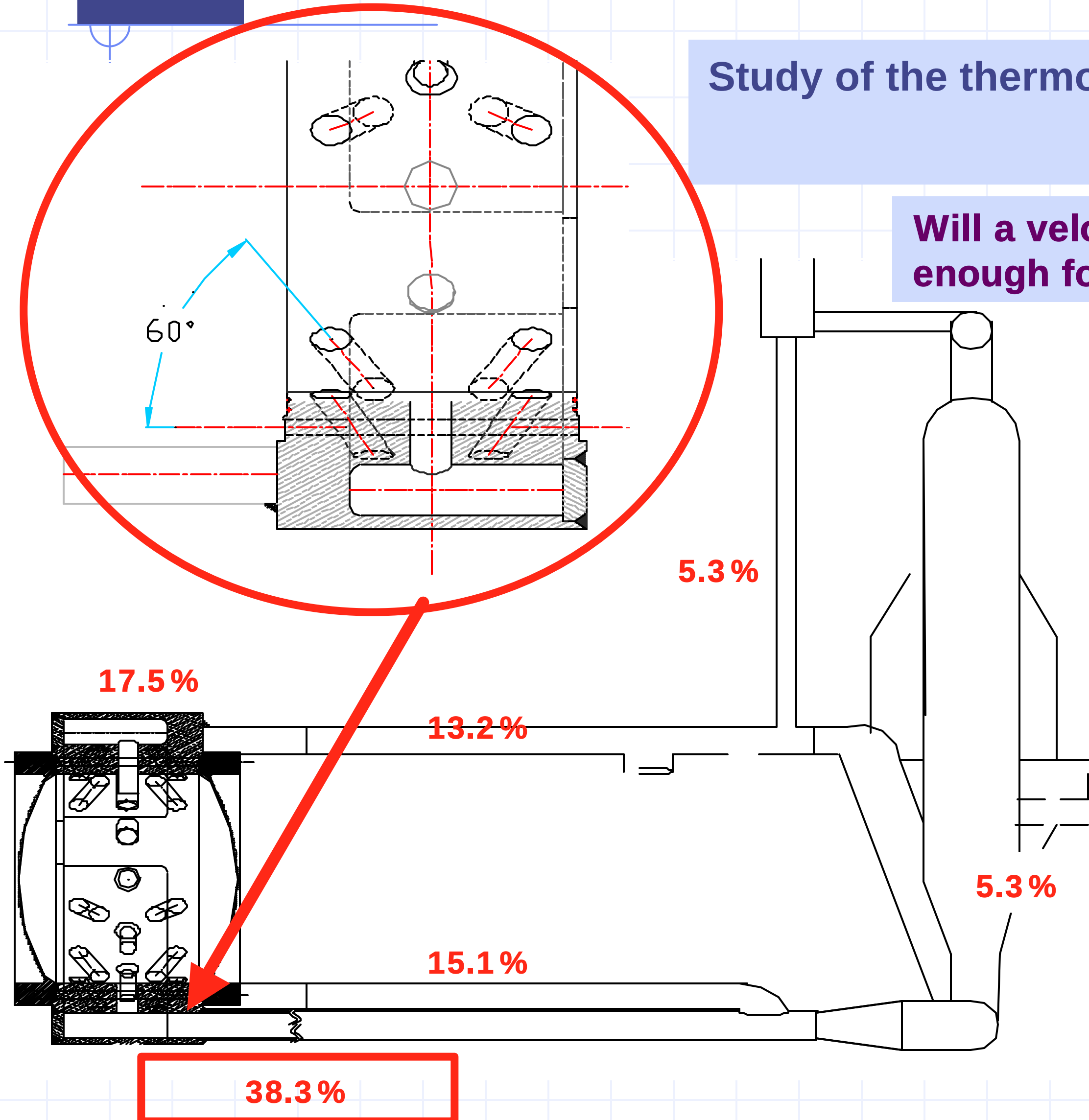
1. **Simulate MTA manifold geometry**
2. **Simulate beam at 150 W (vol. deposition, ø10mm, 3 sigma gaussian)**
3. **Calculate heat transfer coefficients and temperature distribution for MTA conditions (ΔV ~ 0.5 m/s – 4 m/s)**



Pressure drop calculations

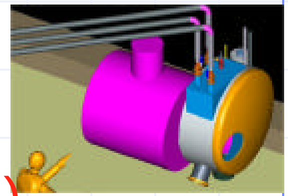
Study of the thermo-hydraulic behavior in LH2 absorber w/ ΔT=1 K

Will a velocity at the nozzle lower than 2 m/s be enough for ionization cooling (i.e. ΔT< 1K)?



- **m_dot=450 g/s**
- **11 supply / 15 return nozzles**
- **Nozzle dia. = 0.6 inch**

- **Nozzle supply velocity = 3 m/s**
- **Maximum allowable ΔP = 0.364 psi**
- **Total ΔP calculated = 0.301 psi**

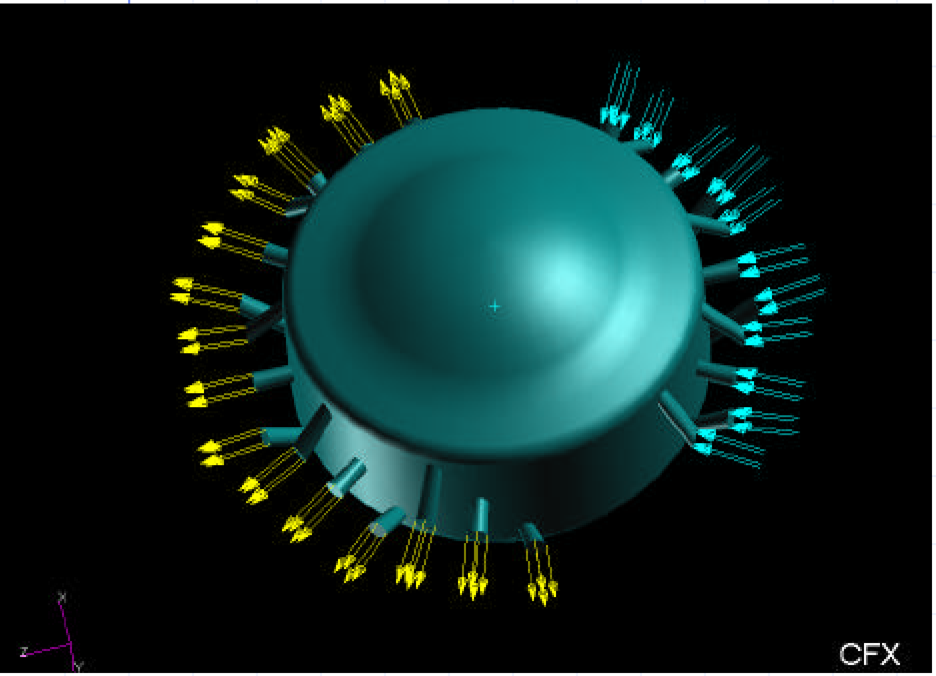


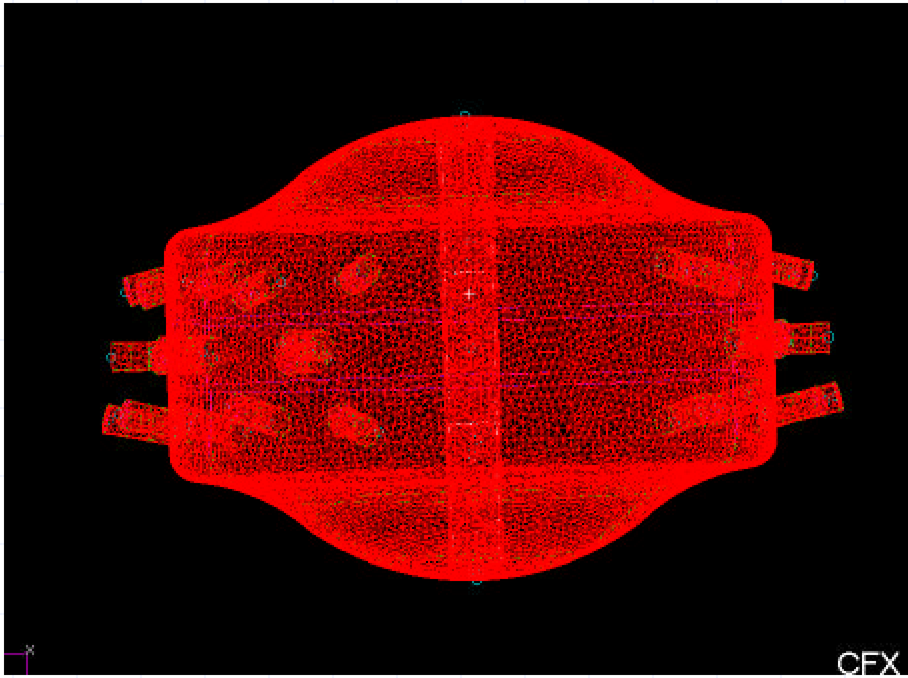
Temperature distribution simulation

By Wing Lau and Stephanie Yang (Oxford)

Model A

- 11 supply nozzles
- 15 return nozzles
- Nozzle diameter: 0.43 inch





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Temperature distribution simulation

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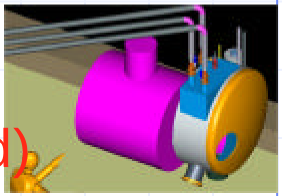
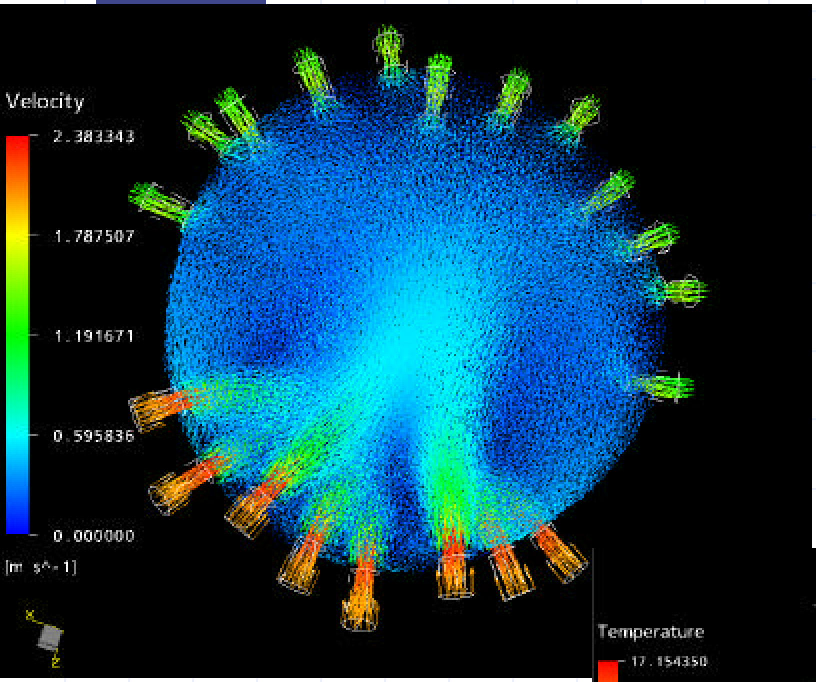
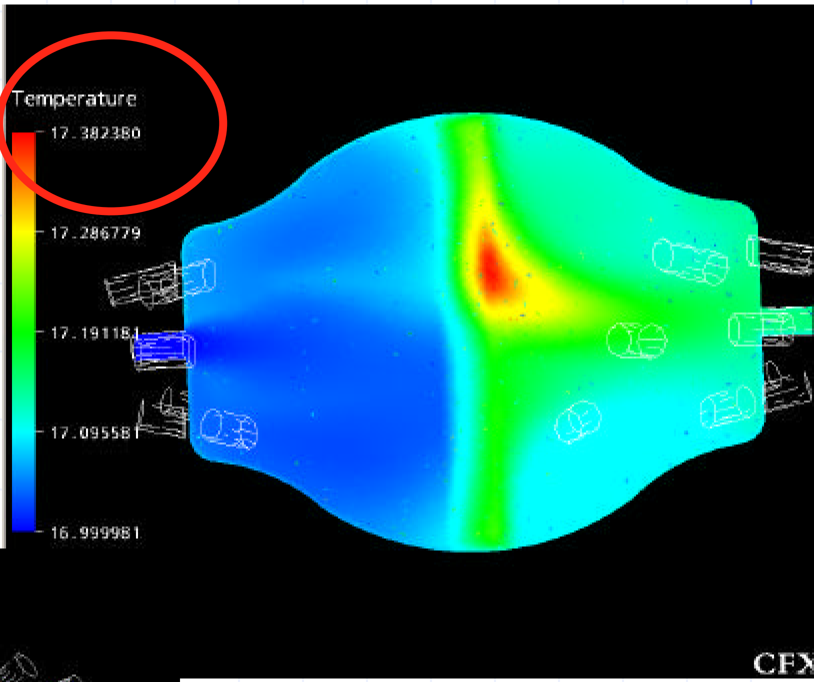
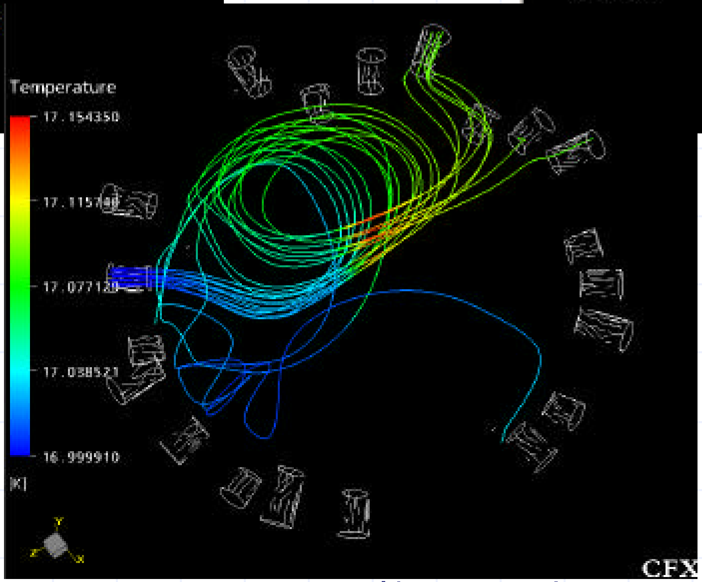




ΔT< 1 K





Model A

V_sup = 2 m/s

But ...

DP = 90 psi

(DP adm.=76psi)

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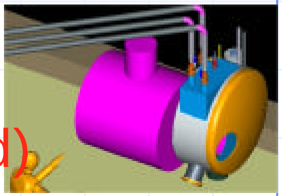
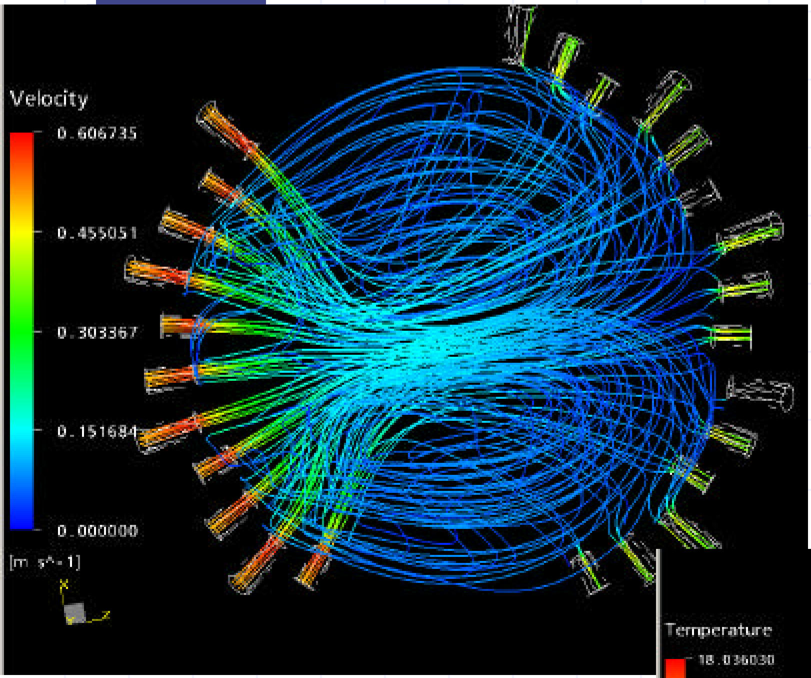
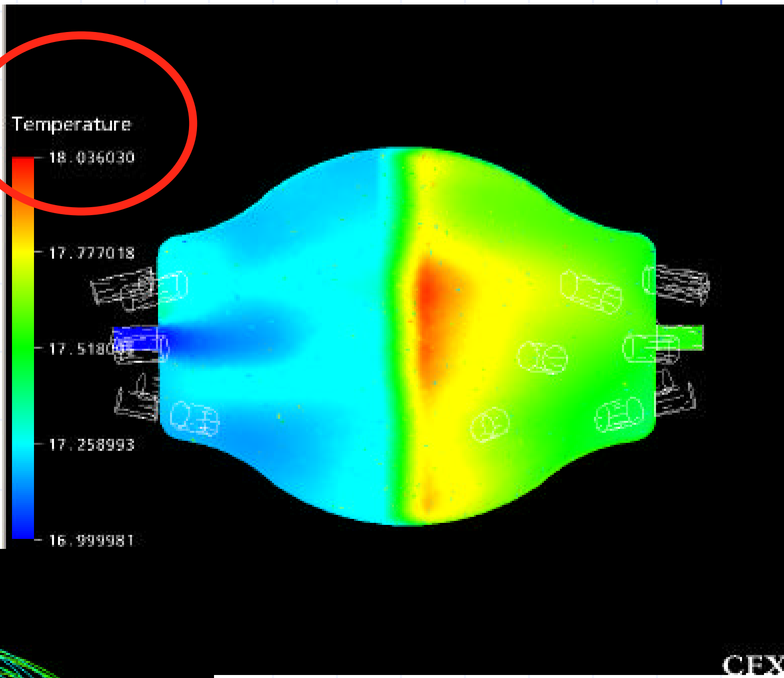
Temperature distribution simulation

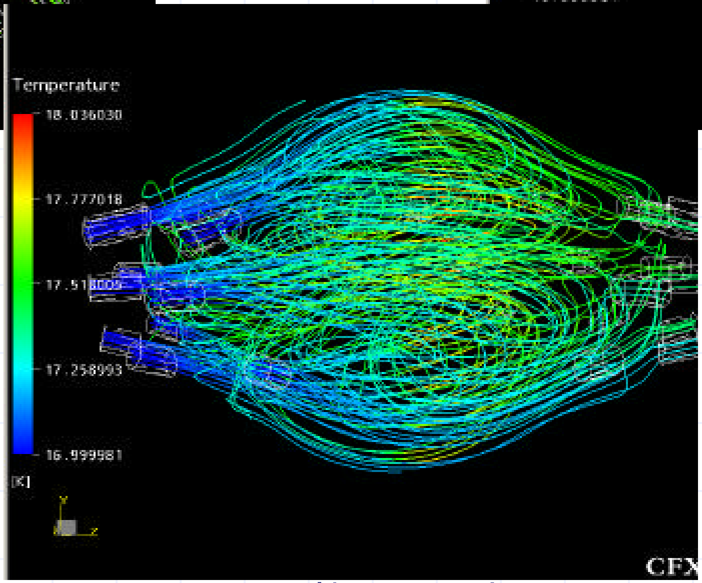
By Wing Lau and Stephanie Yang (Oxford)





$\Delta T < 1$ K





Model A

V_sup = 0.5 m/s

Lower limit for the solution with m_dot = 38 g/s

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Temperature distribution simulation

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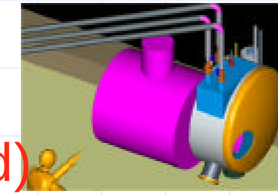
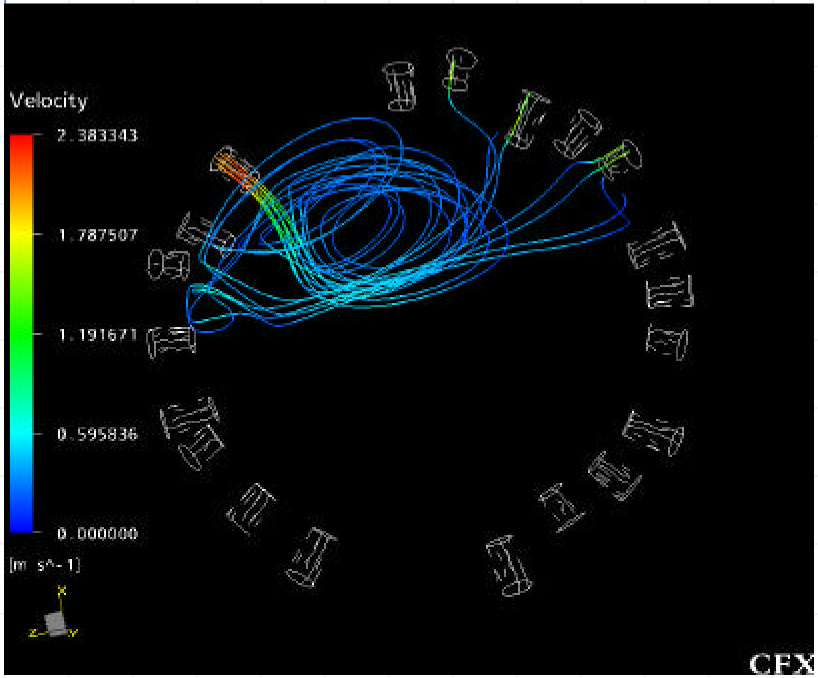
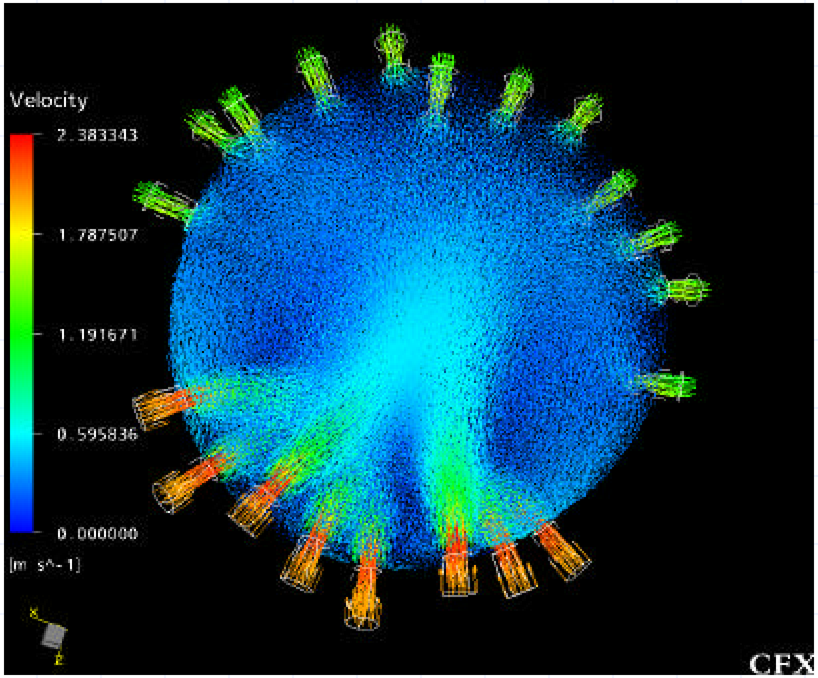


Model B

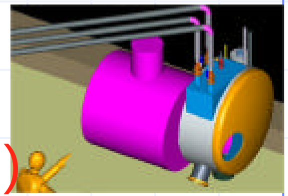
- 8 supply nozzles
- 12 return nozzles
- Nozzle diameter: 0.63 inch

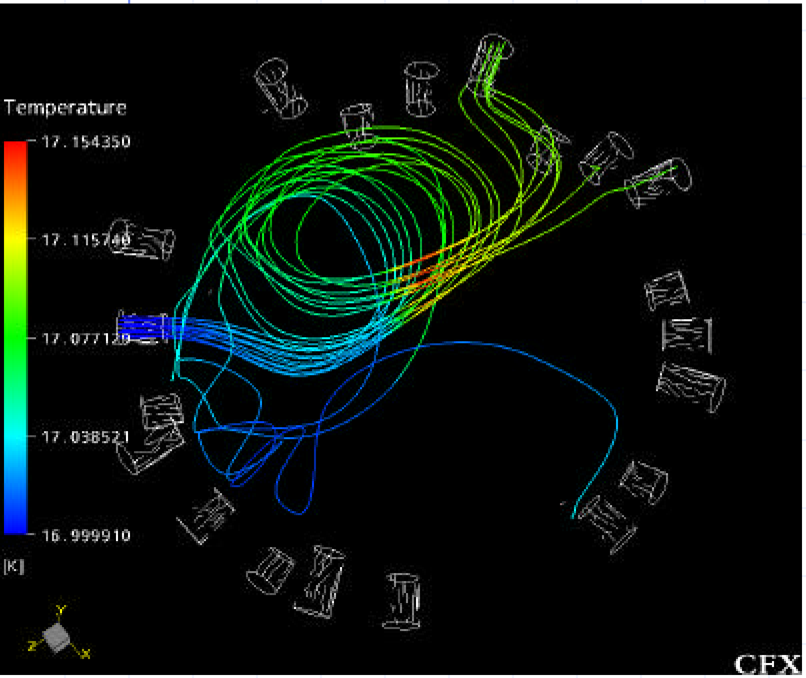




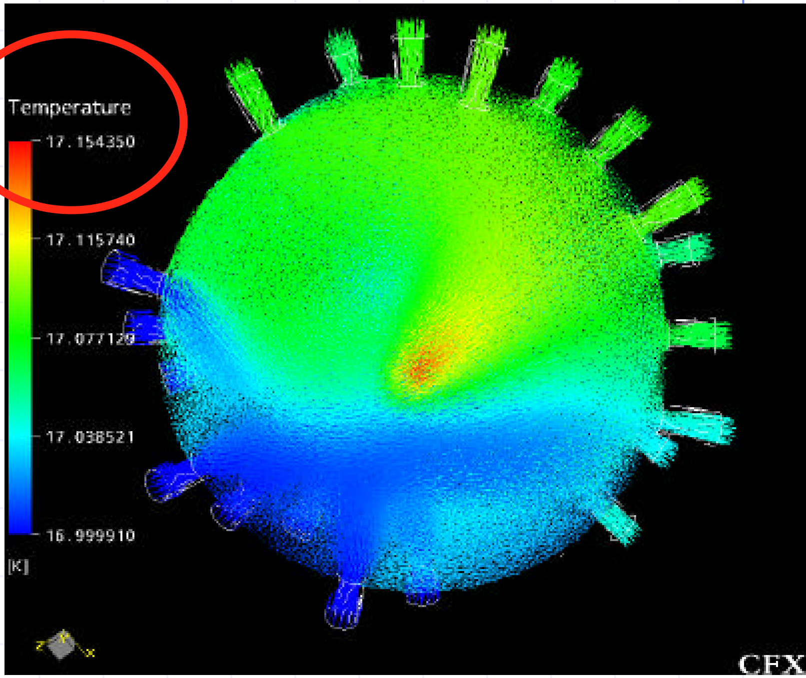
Temperature distribution simulation

By Wing Lau and Stephanie Yang (Oxford)





$\Delta T < 1$ K



Model B

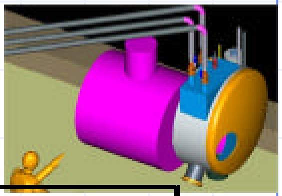
V_sup = 2 m/s

But ...

ΔP = 0.101 psi

(ΔP adm.=0.119 psi)

MTA cooling loop system – Conclusions



		Model A	Model A	Model B	Model C	Model C	Model C
d_nozzle	**inch**	0.43	0.43	0.63	0.60	0.60	0.60
Abs_id	**inch**	22	22	22	21	21	21
#_supply		11	11	8	11	11	11
#_return		15	15	12	15	15	15
m_dot	**g/s**	152	38	215	300	75	450
V_sup	**m/s**	2.000	0.500	2.000	2.000	0.500	3.039
V_ret	**m/s**	1.470	0.370	1.330	0.193	0.370	2.230
D_P	**psi**	**90.000**	**5.900**	**0.101**	**0.137**	**0.009**	**0.301**
D_Ppump	**psi**	76.000	22.000	0.119	0.380	0.036	0.364
D_T	**K**	**0.380**	**1.000**	**0.150**	**?**	**?**	**?**

Cooling loop Focuses:

Proposed Solution: 11 supply/15 return, Dia 0.6”

The Model A proves that ΔT=1K is achieved if nozzle velocity is 0.5 m/s

Therefore any configuration with at least 26 nozzles, larger then 0.43 inch diameter will meet our requirement.

Model C will permit us to cross-check the current solution.

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Process Instrumentation Diagram